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THE RELATION BETWEEN THE BLUENESS OF THE SKY AND (A) THE POLARITY OF THE AIR (B) THE GRADIENT WIND

By J. H. BRAZELL, M.Sc.

with an appendix on

OBSERVATIONS OF THE BLUENESS OF THE SKY AT ABERDEEN, VALENTIA AND KEW

By J. S. FARQUHARSON, M.A.

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THE RELATION BETWEEN THE BLUENESS OF THE SKY, AND (*a*) THE POLARITY OF THE AIR (*b*) THE GRADIENT WIND.

By J. H. Brazell, M.Sc.

In 1925 Prof. F. Linke, Director of the Universitäts-Institut für Geophysik und Meteorologie, Frankfurt a./Main, approached a large number of meteorological services with the request that they should undertake observations of the blueness of the sky. A description of the scale used and of the method of using it for making observations was given by Ostwald and Linke (1)* in 1928. The Meteorological Office, London, was among those approached, and observations were begun in June 1926 at Cattewater (Plymouth), Cranwell and Croydon. These observations have been discussed by Farquharson (2) in a Professional Note published in 1936.

During the year May 1934 to April 1935 observations of the blueness of the sky were made at Kew, Valentia and Aberdeen; the observations being made about midday. The relationship between these observations at Aberdeen, Valentia and Kew and the earlier observations at Cattewater, Cranwell and Croydon is discussed by Mr. Farquharson in an appendix to this paper. The aim of this present investigation, which was suggested by Lt.-Col. E. Gold, is to correlate these observations of the blueness of the sky with the polarity of the air and the gradient wind. In this case the "polarity" expresses the type of air mass on the scale:— 0 = tropical air, 1 = very old polar air, 2 = old polar air, 3 = polar air, 4 = arctic or direct polar air. A table giving the blueness of the sky, the polarity of the air and the gradient wind at the three observatories, Aberdeen, Valentia and Kew, during the period May 1934 to April 1935 was prepared and is available in manuscript. It is advisable to consider separately the connexion between blueness and polarity, and blueness and gradient wind.

Considering firstly blueness and polarity; Table 1 gives the average blueness for polarity 0, 1, 2, 3 and 4 at the three observatories.

TABLE I.—AVERAGE BLUENESS OF SKY WITH AIR OF POLARITY 0, 1, 2, 3 AND 4

Aberdeen					
Polarity	0	1	2	3	4
Average blueness	4·8	5·3	6·0	6·7	6·7
No. of observations	14	62	57	45	22
Valentia					
Polarity	0	1	2	3	4
Average blueness	6·2	6·0	6·5	6·4	6·7
No. of observations	23	77	46	29	6
Kew					
Polarity	0	1	2	3	4
Average blueness	5·7	4·9	5·4	5·0	5·4
No. of observations	20	46	23	13	7

* The numbers in brackets refer to the bibliography on p. 8.

These results are graphed in Fig. 1. It is noticeable that in Aberdeen there is a progressive increase in blueness as polarity increases from 0 to 4. This increase in blueness with polarity is also shown in the Valentia observations, but it is not so well marked as it is in the

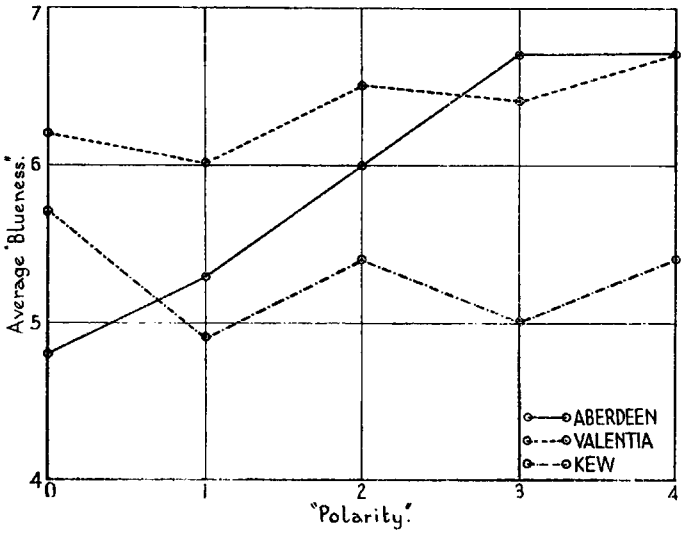

FIG. 1.

Aberdeen observations. On considering the values for Kew, it is seen that the increase of blueness with polarity disappears, and no definite relationship appears to exist between blueness and polarity.

The subjective nature of observations of the blueness of the sky has been commented on by Farquharson (2) and by many observers who have used the scale. The personal factor will to some extent be decreased if extreme values are considered. Table II gives the occurrences of maximum and minimum blueness together with the corresponding polarity and gradient wind during the year at the three observatories. The deepest shade of blue at Aberdeen was shade 9, which was observed on 7 occasions; the lowest shades of blue observed were shade 2 which occurred 3 times and shade 3 which occurred 8 times. At Valentia the deepest shade of blue was shade 8, which was observed on 14 occasions; the lowest shades of blue observed were shade 3 which occurred once and shade 4 which occurred 10 times. The deepest shade of blue at Kew was shade 7, which was observed on 10 occasions; while the lowest shades of blue observed were shade 2 which occurred twice and shade 3 which occurred 6 times.

In considering polarity, figures 0 and 1 were taken as representing air which was tropical in character and figures 3 and 4 as representing air which was polar in character. Accordingly in the case of

TABLE II(*a*).—MAXIMUM BLUENESS WITH CORRESPONDING POLARITY AND GRADIENT WIND

Blueness	Polarity	Gradient wind		Blueness	Polarity	Gradient wind	
		°	m.p.h.			°	m.p.h.
			Aberdeen				
9	2	350	30	9	3	290	50
9	2	270	25	9	4	300	40
9	1	240	15	9	4	270	45
9	2	290	20				
			Valentia				
8	2	260	30	8	2	290	25
8	3	240	55	8	3	10	25
8	2	240	40	8	4	360	30
8	3	340	25	8	3	330	25
8	0	240	25	8	2	10	45
8	1	180	30	8	2	180	30
8	2	250	30	8	3	30	15
			Kew				
7	2	280	20	7	0	150	15
7	4	290	20	7	0	220	25
7	2	60	10	7	2	250	25
7	1 or 2*	280	40	7	0	190	30
7	2	350	15	7	4	280	35

* In these cases it was impossible to determine whether the air mass was very old polar (1) or old polar (2).

TABLE II(*b*).—MINIMUM BLUENESS WITH CORRESPONDING POLARITY AND GRADIENT WIND

Blueness	Polarity	Gradient wind		Blueness	Polarity	Gradient wind	
		°	m.p.h.			°	m.p.h.
			Aberdeen				
3	1	230	15	3	0	180	15
2	2	300	25	3	1	200	30
2	1	90	10	3	4	360	35
3	1	180	10	3	2	240	40
2	1	160	10	3	1	270	15
3	1	210	25				
			Valentia				
4	1	50	10	4	1	360	25
4	1	50	20	3	0	150	10
4	1 or 2*	90	10	4	3	260	30
4	1	90	10	4	1	90	15
4	1	40	10	4	0	60	10
4	1	90	5				
			Kew				
2	1	30	35	3	2	140	25
3	1	80	25	3	1	270	15
2	1	Calm		3	2	270	15
3	1	80	5	3	2	250	45

* In these cases it was impossible to determine whether the air mass was very old polar (1) or old polar (2).

maximum blueness the following percentages were obtained (the percentage in each case being expressed as percentage of number of observations of maximum blueness and not percentage of total number of observations); Aberdeen 43 per cent. with polar air, 14 per cent. with tropical air; Valentia 43 per cent. with polar air, 14 per cent. with tropical air; Kew 20 per cent. with polar air, 30 per cent. with tropical air. With the exception of Kew, maximum blueness occurs more frequently with polar than with tropical air. Considering minimum blueness the following percentages were obtained; Aberdeen 73 per cent. with tropical air, 9 per cent. with polar air; Valentia 82 per cent. with tropical air, 9 per cent. with polar air; Kew 62·5 per cent. with tropical air, 0 per cent. with polar air. The number of occasions on which minimum blueness was observed with polar air is very small.

Loewe (3) made observations of the blueness of the sky during aircraft flights and found that blueness increases from 6·4 at the ground to 11·8 at 6Km. This increase in blueness is due to diminution of atmospheric pollution with height, therefore blueness as observed from the ground is to a great extent dependent on atmospheric pollution. Considering the three observatories, atmospheric pollution is in general greater at Kew than at the other two observatories, and this fact explains why blueness was generally greater at Aberdeen and Valentia than at Kew and may also explain why correlation between blueness and polarity is lower at Kew than at the other two observatories. It is noticed that maximum blueness is higher at Aberdeen, 9, than at Valentia, 8, although industrial pollution is expected to be greater at Aberdeen than Valentia. At Valentia the prevailing wind is off the sea so that the air is rich in salt particles. These salt particles probably produce a whitening of the sky, and the lower maxima at Valentia can be attributed to the presence of these salt particles.

Linke (4) suggested that convection should reduce the blueness of the sky while Thomson (5) observed that in Apia during the dry season convection causes a whitening of the sky. The observations at Aberdeen, Valentia and Kew were made about midday when convection is approaching a maximum. Convection increases with polarity so that the effect would be to decrease blueness when polar air was present while not appreciably affecting blueness when tropical air was present. This probably explains why maximum blueness occurs with tropical as well as with polar air. Summing up, the following points arise :—

(1) Deep blue skies occur with tropical as well as with polar air but they occur more frequently with polar air.

(2) Pale blue skies nearly always occur with tropical air.

(3) The blueness of the sky tends to increase with the polarity of the air.

It appears that a correlation between blueness of the sky and polarity of the air does exist but the degree of correlation is not high. The degree of correlation increases as atmospheric pollution decreases. This result agrees with that obtained by Linke (6) who ascertained that in Lapland the sky had a deeper blue colouring with polar air than with sea or tropical air. It is thought that the correlation between blueness of the sky and the polarity of the air would be greater if the observations were made from an aircraft at a height of about 4,000 ft. and not from the ground.

Now considering the blueness of the sky and the gradient wind, Table III gives the average wind speed for the range of blueness 2 to 9 at the three observatories, Aberdeen, Valentia and Kew.

TABLE III.—AVERAGE WIND SPEED CORRESPONDING TO BLUENESS, 2—9

Aberdeen

Blueness	2	3	4	5	6	7	8	9
Average wind speed (m.p.h.)	15	23	24	22	25	26	28	32
No. of observations	3	8	34	37	61	35	40	7

Valentia

Blueness	..	3	4	5	6	7	8	..
Average wind speed (m.p.h.)	..	10	14	22	23	24	31	..
No. of observations	..	1	10	24	79	77	14	..

Kew

Blueness	2	3	4	5	6	7	..	..
Average wind speed (m.p.h.)	17	22	20	20	21	23	..	..
No. of observations	2	6	20	34	44	10	..	..

These results are graphed in Fig. 2. In the case of Aberdeen and Valentia there is a definite increase of blueness with wind speed, but in the case of Kew this increase of blueness with wind speed is not so well marked. In general the blueness of the sky increases with wind speed, but this effect may be masked by atmospheric pollution.

It is interesting to consider what relationship exists between blueness of the sky and the direction of the gradient wind. Since the blueness of the sky depends on atmospheric pollution there should be a close connexion between blueness and wind direction. It is advisable to consider each observatory separately.

Aberdeen observatory is situated to the north of the city and winds between 130° and 240° will convey pollution from the city as well as from the industrial areas surrounding Glasgow and Newcastle. Winds from other directions will produce very little atmospheric pollution. Maximum blueness, 9, was observed at Aberdeen on

seven occasions and on all these occasions the wind direction was not between 130° and 240°. Blueness 4 and below occurred 45 times, on 27 of which the wind direction was between 130° and 240°.

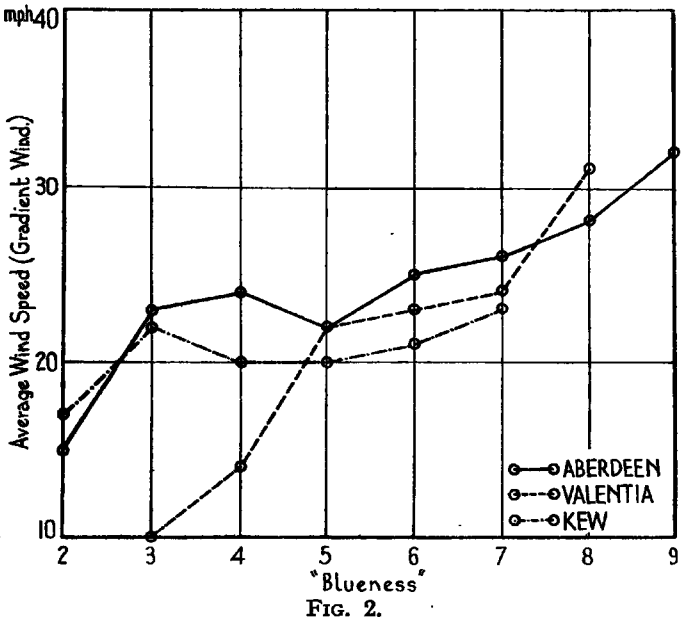

FIG. 2.

In the case of Valentia the observatory is far away from smoky industrial areas but air which has had a long track over the British Isles will to some extent be polluted. Winds from between 30° and 120° will be most favourable for atmospheric pollution. In general winds from other directions should be fairly free from pollution. Maximum blueness, 8, was observed at Valentia on 14 occasions and on all those occasions the wind direction was not between 30° and 120°. Blueness 4 and below occurred 11 times and on 8 occasions the wind was from the sector 30° to 120°.

Kew is a much more difficult case to deal with, being situated in the densely populated and highly industrialised area surrounding London. Winds from all directions will be bearers of atmospheric pollution but some will convey more pollution than others. Since Kew is situated in the western part of greater London pollution will in general be less with westerly than with easterly winds. Pollution will be heaviest with winds from the sector 20° to 120° and it is interesting to note that out of the ten occasions on which blueness was a maximum, 7, only on one occasion was the wind in the sector 20° to 120°.

On examining the results obtained for the three observatories it is seen that a close relationship does exist between blueness of the sky and the direction of the gradient wind.

Summary.—Observations of the blueness of the sky at Aberdeen, Valentia and Kew have been examined in relation to (*a*) polarity of the air and (*b*) gradient wind.

With regard to the relationship with polarity, it is found that at Aberdeen and Valentia the blueness of the sky increases with the polarity of the air, the increase being well marked at Aberdeen. At Kew this increase of blueness with polarity does not exist. The fact that the blueness of the sky does not increase with polarity at Kew, as it does at the other two observatories, can be attributed to the much greater atmospheric pollution at Kew.

With regard to the relationship with gradient wind, it is found that at Aberdeen and Valentia there is a definite increase of blueness as wind speed increases. This increase of blueness with wind speed is not so well marked at Kew. At the three observatories there is a close connexion between blueness of the sky and wind direction. In general winds from populated and industrial areas produce pale blue skies and winds from rural areas produce deep blue skies.

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APPENDIX.—OBSERVATIONS OF THE BLUENESS OF THE SKY AT ABERDEEN, VALENTIA AND KEW

By J. S. FARQUHARSON, M.A.

The observations at the three observatories, broadly speaking, show similar variations in blueness to those noted in the earlier series of observations at Cranwell and Croydon. The outstanding feature is that, though two of the observatories are on the coast and though Valentia might be expected to be at least as free from atmospheric pollution as Cattewater, at none of them were as deep shades of blue observed as at Cattewater. The surprising fact emerges that even Croydon experienced skies of far deeper blue than either Aberdeen or Valentia.

The deepest shades of blue observed at various places were as follows :—

Aberdeen	9	Konigsberg	12
Cattewater	14	Lübeck	12
Cranwell	12	Apia	12
Croydon	11	Tabarz	10
Kew	7	Washington	8
Valentia	8	Sonnblick	14

At all three observatories the percentage annual frequency is a maximum for shade 6, as it was at Cranwell and Croydon, but this frequency is much higher at Kew and Valentia than at Aberdeen.

The " spread " of the frequencies is so much smoother at Aberdeen than at either of the other observatories, that one is inclined to the view, that the experience gained by the specialisation in the observation of optical phenomena there has helped in the more effective use of the colour scale at Aberdeen than elsewhere.

The abrupt change in percentage frequency for the year from 8·6 for shade 7 to nil for shade 8 at Kew, and from 6·8 for shade 8 to nil for shade 9 at Valentia, as compared with the more gradual " tailing off " of frequencies at Aberdeen, also suggests the influence of the personal factor. On the other hand, the annual percentage frequency for shade 7 at Aberdeen is less than for shade 6 or 8, suggesting the effect noted at Cattewater, (2) namely the distaste for, or difficulty in using, the odd shade as compared with the even shades on either side. It may be that this effect only shows up when there is a large number of observations spread over the three or more shades affected.

As regards blueness of the sky, Aberdeen appears to occupy a mean position between Kew and Valentia. This is shown by the average blueness, which is 6·0 at Aberdeen as compared with 5·2 at Kew and 6·3 at Valentia. Also, the difference in frequency from shade 6 to shade 5 at Kew is small compared with the variation from shade 6 to shade 7, while at Valentia the difference in frequency from shade 6 to shade 5 is much larger than that from shade 6 to shade 7. At Aberdeen the differences in frequency on either side of shade 6 are almost equal. If the atmospheric pollution is the chief factor affecting blueness of the sky one would expect the values at Aberdeen to be intermediate between those at Kew and Valentia.

Taking the values for noon at Croydon, the average blueness at Kew and Croydon is as follows :—

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Croydon	5·8	5·7	6·6	6·3	6·2	6·6	6·1	6·4	6·3	6·2	6·2	5·3	6·2
Kew	4·4	4·7	5·1	6·2	5·3	5·2	5·6	5·4	5·3	5·7	4·5	4·0	5·2

The annual variation of the two places is similar in that blueness is less in the winter months than in the other months. The peaks at March and June in the annual curve of blueness for Croydon are shifted along to April and July at Kew. The sharpness of the April peak at Kew may be partly due to the paucity of observations, but it is interesting to note that the spring maximum for blueness runs through all the British observations and through some of those made on the continent. Another similarity in the annual variation at Kew and Croydon is that at both, the highest shade observed occurred most frequently in the summer months.

At Aberdeen, the minimum average blueness is 4·8 in June. Linke (1) suggested that convection should reduce the blueness of the sky and this might explain the Aberdeen minimum, but the same factor should be operative at all three observatories. In this connexion it is noteworthy that though the blueness is not a minimum in June at Kew, shade 2 was observed there only in May and June, while at Valentia shade 4 was more frequently observed in June and July than in any other month.

At Valentia the range of variation in average blueness throughout the year is much less than at Aberdeen or Kew. With over 76 per cent. of the observations divided between shades 6 and 7, the intensity of this maximum frequency is reminiscent of that for the shades 6, 7 and 8 at Cranwell. The sum of the frequencies for these three shades at Cranwell bore the ratio 2·66 : 1 to the sum of the frequencies for all the other shades put together, the corresponding ratio at Croydon being 1·53 : 1.

In short, these observations at the three observatories show variations in the various shades of blue substantially similar to those found at Cranwell and Croydon.

Loewe (2) making observations from an aeroplane, showed that the blueness of the sky as seen from the ground, and its variation, were dependent on what happened in the lowest kilometre, and observations on the Sonnblick and other mountains rather support this view. There is some evidence of diurnal variation in blueness. If it is accepted, then unless polarity undergoes a diurnal change, it should be possible, theoretically, to observe two different shades of blue at different times on the same day in air of given polarity.

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